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Are the Color Gamuts of CRT and LCD Triangular? An Experimental Study

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ABSTRACT

Color LCD (Liquid Crystal Display) has been widely used for personal computers (PC) and video monitors because of its light weight, small volume, low power consumption and so on. Color reproductions for LCD panels are different from that of CRT (Cathode Ray Tube) display. This study describes the difference of color gamuts in different luminance level and the accuracy of color between CRT and LCD. In the present study, the reproduction color gamuts on the chromaticity diagram are measured in three types of displays, including two CRT types (BARCO Reference Calibrator Plus and ViewSonic PT775) and one LCD type (NEC MultiSync LCD 200). In the experiment, the tristimulus values XYZ for the combinations of three primary colors R(red), G(green), B(blue) were measured by varying the input digital levels. The digital levels which varied from 0 to 255 in every primary color were equally divided into 17 stages, including 0 and 255, and thus the tristimulus values of 4913 colors at each display were measures. Size and shape of color gamuts varied with the luminance, sampling distribution and color difference of LCD and CRT will be discussed. The higher the value of Y, the smaller the area of the color gamut, no matter which display type performed. The area of the color gamut of LCD is smaller than that of CRT in most levels of luminance. This paper discovered that some special patterns exist in color gamut diagrams. Final, relationships among patterns have been clarified for characterizing the color gamuts of displays.

1. INTRODUCTION

Color LCDs are more and more popular in the computer market. If the price of LCDs can drop down, LCD will substitute CRT which are the mainstream of the d*isplay market at the present time, because of its light weight, small volume, low power consumption and so on. And the display panels of notebooks are all used LCDs. Color reproduction for LCD panels are different from that for CRTs, so this makes the differences of the gamut, color difference and sampling distribution between different type displays. These differences will influence legibility, color matching, user's task performance and feeling, and so on. In contrast to CRTs, LCDs have sharp edged pixels being therefore more suitable to produce sharp edged horizontal and vertical lines. Moreover, pixels of LCD are not subject to spatial instabilities such as jitter. Uncontrolled external electromagnetic radiation may induce jitter at a CRT reducing legibility of characters displayed. Visibility of flicker may be less at LCD because of a more favorable time-course of single pixel luminance. Most CRT displays are equipped with phosphors with a short persistence-time[1]. Yukio[2] indicated that the color gamut and correlated color temperatures for a LCD panel change according to the input digital level. Hence, the CRT does not change its color gamut and corrected color temperature. It is shown that the LCD reveals the bluish color reproductions. Wright[3] compared the resolution and legibility of TFT-LCDs and that of CRTs. Although there are some researches about comparing LCD and CRT, there are few researches adverting to the comparisons of color gamuts between LCD and CRT. This paper will focus on measuring color gamuts with field study, not computing.

Pointer[4] indicated that the gamut of chromaticities of standardized set of color-television receiver phosphors was a triangle. Up to present, many manufacturers use primary color phosphor (RGB) to depict the triangular color gamuts of displays on 2-D plots. There is no need to emphasize that method does not consider about the lightness. Theoretically, transection of color gamut is not always triangular from dark to white. In this paper, we measured the color gamuts of three different type displays, one LCD type display and two CRT type displays. The color reproduction characteristics for a LCD

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and CRTs have been analyzed. It is found that the color gamuts are changed with the change of luminance, and there is a special relationship between RGB color space and CIE (Lu'v') color space. This relationship will be useful of color correction. The color difference of CRT and LCD is analyzed, too.

2. METHOD

The gamuts of three types display, including two CRT types and one LCD type, were measured by the colorimeter, PR650. Two CRT displays, BARCO Reference Calibrator Plus and ViewSonic PT775, and one LCD display, NEC MultiSync LCD 200, were examined. The BARCO display has been calibrated with calibrator talk. The display card used in the experiment is Matrox Millennium G400-DH.

The resolution of display is 1204*768. The color is set as 24 bits true color. The background is MS Windows98 desktop. A color specimen, which is an 800*600 pixel rectangle, is shown in the center on the display. The specimen fixed for 3 seconds before measured in all dark room. The measured distance between the display and the colorimeter is 40 cm, and the diameter of measured dot is 4 mm. The tristimulus values (X, Y, Z) for the combinations of three primary colors are measured by varying the input digital levels. The digital levels changed from 0 to 255 in every primary color are equally divided into 17 stages, including 0 and 255, and thus the tristimulus values of 4913 (17*17*17) colors at each display are measured.

3. RESULTS

3.1. Color gamuts

The tristimulus values (X, Y, Z) are transformed to CIE 1976 (u', v'). The gamuts of three displays are shown in Figure 1. The gamut of LCD is the smallest in the three displays, and its shape is not a typical triangle. LCD's gamut in blue area is smaller than that in CRTs, but LCD's gamut is wider than CRT in cyan to blue part.

Figure 1 is a 2-D projection of gamut, and it does not illustrate the difference of gamut in a variety of luminance. For observing the variation of gamut at different luminance, this study divided luminance into five levels ($0<Y\leq20$, $20<Y\leq40$, $40<Y\leq60$, $60<Y\leq80$, $80<Y\leq100$). The results are shown in Figure 2, Figure 3 and Figure 4. According to these figures, the color gamuts are triangular only at $0<Y\leq20$.

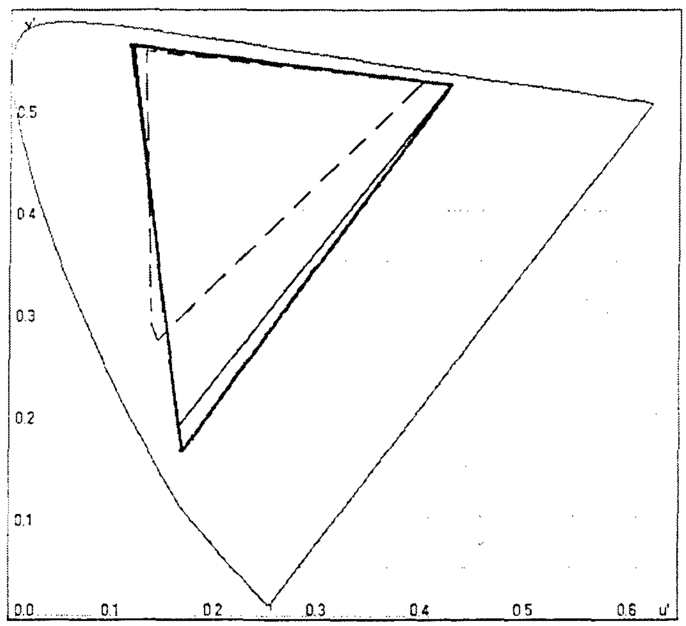

Figure 1. The gamuts of the three displays: Ruggedness-BARCO, Hairline-ViewSonic PT775, Leader- NEC MultiSync LCD 200.

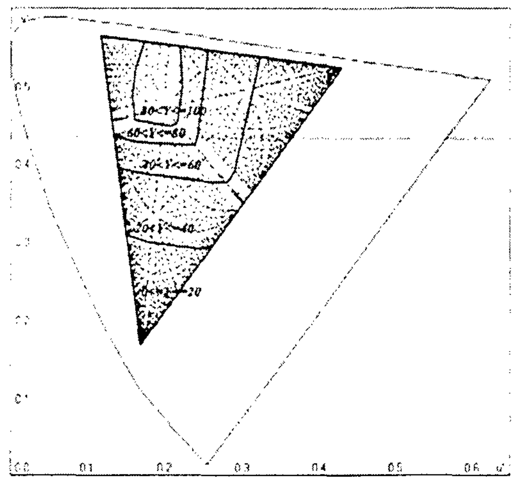

Figure 2. Boundaries of color gamuts of BARCO at different luminance levels.

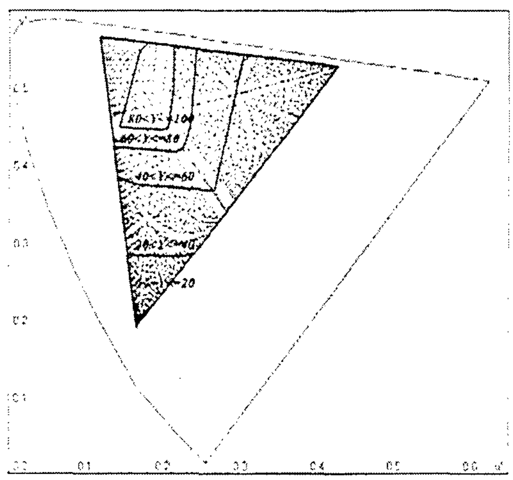

Figure 3. Boundaries of color gamuts of ViewSonic PT775 at different luminance levels.

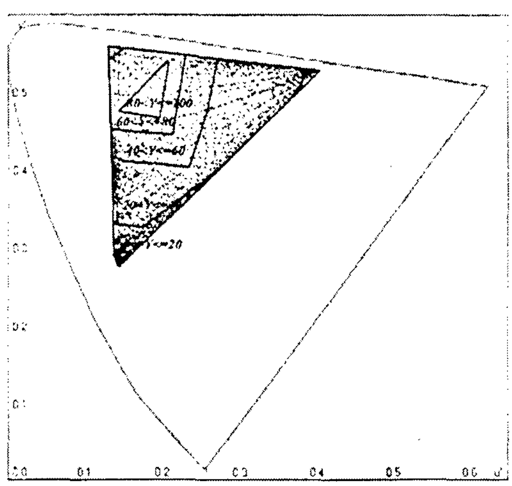

Figure 4. Boundaries of color gamuts of NEC MultiSync LCD 200 at different luminance levels.

3.2. Sampling distribution

As Figure 2 and Figure 3 shown, the sampling distribution performs in regular form on CRT displays. There are several characteristic patterns of CRTs, and to find these patterns can help us to understand CRTs more. To take BARCO as an example, there are thirteen points selected as the characteristic patterns of BARCO. These points are shown in Figure 5.

According to these characteristic patterns, we analyzed their (u', v') values and determined the values of (u', v') ± 0.005 as ranges. Next, We tried to search for measured specimens matching the condition. The results listed in Table 1. Surprisingly, those measured data fitted to a characteristic pattern were colinear. It revealed that every characteristic pattern represented a line in RGB color space.

Table 1. The RGB values of BARCO characteristic patterns

Characteristic pattern	Color	u'	v'	R	G	B
R	Red	0.425	0.52375	X>=96	0	0
G	Green	0.12	0.56375	0	X>=64	0
B	Blue	0.17125	0.17125	0	0	X>=128
O	White	0.20875	0.55125	X	X	X
D	Magenta	0.30125	0.45127	X	0	X
E	Cyan	0.13375	0.45125	0	X	X
F	Yellow	0.20875	0.55125	X	X	0
H	Light Green	0.145	0.5325	X/2	X>=64	X/2
I	Rose	0.305	0.49375	X>=96	X/2	X/2
J	Light blue	0.185	0.335	X/2	X/2	X>=96
M	Mauve	0.625	0.395	X	X/2	X
N	Aqua	0.15125	0.45625	X/2	X	X
P	Cream	0.20625	0.53125	X	X	X/2

X is the integer between 0 and 255.

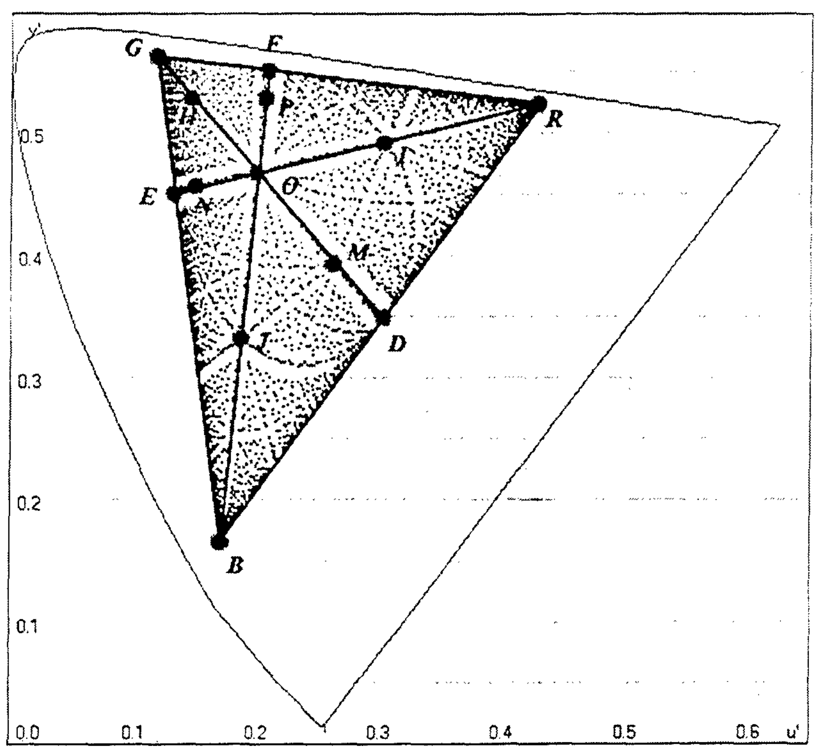

Figure 5. The characteristic patterns of BARCO's color gamut.

3.3. Color difference

To know which type of the three displays, BARCO, ViewSonic PT775 and NEC MultiSync LCD 200, presented the most accurate color, $\Delta E_{CIE}(L^*u^*v^*)$ of them was used to compare their color difference. The formulas that were used is shown below. In Addition, sRGB color space was as reference and D65 was the reference white.

$$L^* = 116(Y/Y_0)^{1/3} - 16 \quad Y/Y_0 > 0.01$$
$$u^* = 13L^*(u' - u_0')$$
$$v^* = 13L^*(v' - v_0')$$

and

$$u' = \frac{4X}{X + 15Y + 3Z}$$
$$v' = \frac{9Y}{X + 15Y + 3Z}$$
$$u_0' = \frac{4X_0}{X_0 + 15Y_0 + 3Z_0}$$
$$v_0' = \frac{9Y_0}{X_0 + 15Y_0 + 3Z_0}$$

X_0、Y_0、Z_0 are the tri-stimulus values of D_{65}.

$$\Delta E_{CIE}(L^*u^*v^*) = [(\Delta L^*)^2 + (\Delta u^*)^2 + (\Delta v^*)^2]^{1/2}$$

After computing, results revealed that NEC MultiSync LCD 200 had the largest color difference, and BARCO had the smallest color difference among these three types of display, listed in Table 2. Even ViewSonic PT775 was much better than NEC MultiSync LCD 200. CRT type displays were better than LCD type displays in the field of color difference.

Figure 6, Figure 7 and Figure 8 illustrate that the spots were the least color difference among the three displays in individual display. BARCO has the most spots (75.03%) with the least color difference. The spots in ViewSonic PT775 (23.06%) distributed over yellow, green, Cyan and Magenta. In addition, the spots in NEC MultiSync LCD 200 (3.51%) distributed over several lowest lightness and aquamarine were the worst. These results were reasonable. BARCO has been calibrated as a reference display or was used in the professional field of colors. It had good accuracy in color reproduction.

Table 2. Mean and standard error of ΔE

	NEC MultiSync LCD 200	ViewSonic PT775	BARCO
$\text{Mean}_{\Delta E}$	27.68	9.94	6.37
$\text{Standard Errors}_{\Delta E}$	15.59	4.47	3.68

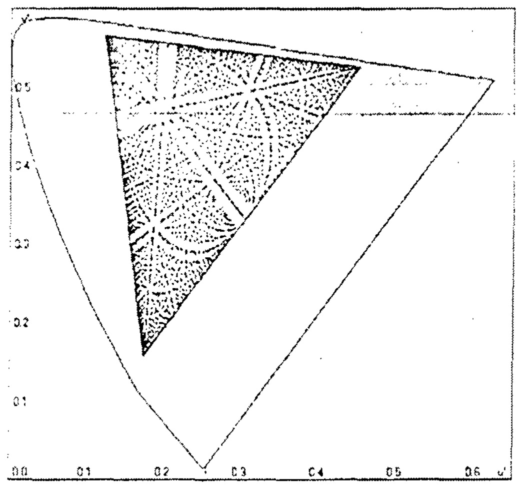

Figure 6. The spots were the least color difference among the three displays (BARCO)

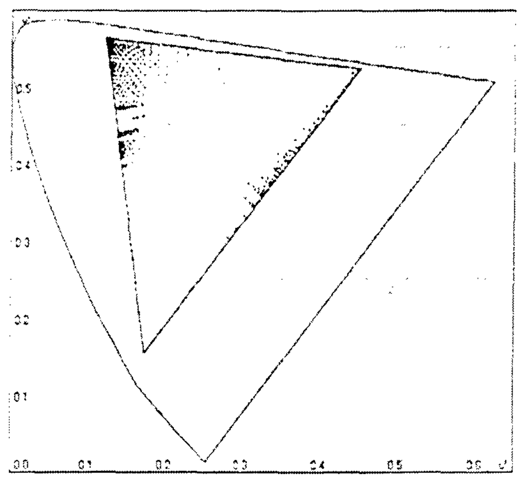

Figure 7. The spots were the least color difference among the three displays (ViewSonic PT775)

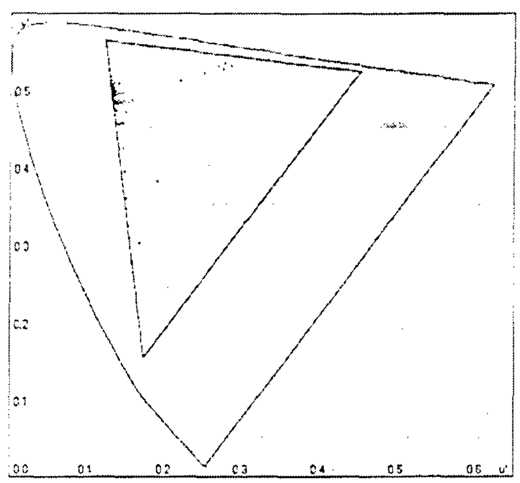

Figure 8. The spots were the least color difference among the three displays (NEC MultiSync LCD 200)

4. DISCUSSION

As **Figure 1** depicts, the gamut in LCD was smaller than that in CRT, and LCD could not reproduce more saturate color in blue and red than CRT could. According to Figure 2, Figure 3 and Figure 4, the higher the luminance, the smaller the gamut area. But, is this always true? The gamut of the value of Y between 0 and 20 was analyzed fine. Take BARCO as an example. The biggest area of gamut appears when the value of Y was between 2 and 8. If the value of Y reduced from 2 to 0, the area of gamut reduced rapidly. It could be found that saturate green and yellow could be reproduced in high lightness ($Y_{yellow}>80$, $Y_{green}>60$), but red and blue could not. The most saturate red could be reproduced when the value of Y was smaller than 40, and the most saturate blue could be reproduced when the value of Y was smaller than 20. In most lightness, the size of gamut in CRT was bigger than that in LCD, and the green reproduction in CRT was better than that in LCD.

Traditionally, three apexes (RGB) represent the color gamuts of displays, and they formed a triangle. But it can't represent the gamut in a specific lightness. The results of this experiment revealed that the gamut was not triangular in a specific lightness. Is this really a truth? As shown in Figure 4, the shape of gamut was similar with a triangle when the value of Y was 80, but the apexes were not at the positions of R, G and B. They were at the positions of C, M and Y (cyan, magenta and yellow). This is because magenta, yellow and cyan are combined by two of primary colors, and the lightness of them can be gained by adding the lightness of two of primary colors. The shapes of gamut in most lightness were not triangular. Because the size of the gamut was out of the range that the display could reproduced with primary colors, and the part that exceeded would be cut. That is why the shapes of gamut in most lightness looked like quadrangles. The shape of gamut in the LCD varied rapidly with the lightness.

According to Figure 5 and Table 1, the five points (G, H, O, M and D) were on a straight line, and the line could be limned by a formula. Every line through one of the three apexes can be limned by a formula which contains three variables, R, G, B. For example, $LINE_{G, H, O, M, D}$ is evaluated by the following formula,

$$R=B.$$

In addition, $CURVE_{F,I,D}$ can be limned as the following formula,

$$R=G+B.$$ and

$LINE_{G,N,J}$ can be limned as the following formula,

$$B=2R.$$

The relationship between (L,u',v') and sRGB has been clarified, and it will be useful in color correction of CRT. Why is it only useful in CRT, and would it be useful in LCD too? Figure 4 displays that the sampling distribution of LCD is not as regular as that of CRT, and there was no curve that can be seen clearly. The possible reasons why LCD is worse than CRT is color reproduction by different ways, or color reproduction of LCD is not easily controlled.

5. CONCLUSION

There are some conclusions in this paper.

1. The higher the lightness, the smaller the size of gamut. But if the lightness is under a specific low value, the size of gamut will reduce rapidly when the lightness is minified.
2. The size of gamut in LCDs is smaller than that in CRTs. It means that CRTs can reproduce more colors than LCDs can.
3. The shape of gamut in a specific lightness is similar with a triangle, but this shape may be slashed by the capability that the display can reproduce.
4. A plane in RGB color space can form a line or a curve in the CIE (L,u',v') color space map, and this relationship will be useful in color correction. Moreover, these characteristic patterns can evaluate the quality of display, because they involved more information than the primary color.
5. The color difference of CRT is smaller than that of LCD in most color area. It means that there is still plenty of room for improvement of LCD.

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